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ORIGINAL

# Effect of Passive Temperature Therapy of the Femoral Muscles on the Countermovement Jump Performance

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**Objective:** The purpose of this study was to evaluate the effect of passive-acute temperature therapy of the femoral muscle and dynamic warm-up on the countermovement jump performance.

**Method:** Twenty male track and field athletes from national team underwent three treatments applied on the femoral muscles; cold temperature treatment, thermal treatment and dynamic warm-up. The variables extracted at 2 time points (pre-measurement and post measurement) were the temperature of the left and right femoral muscle, displacement & velocity of centre of mass, peak power out, range of motion and moment & power of the knee joint.

**Results:** There was a statistically significant difference in the temperature of the femoral muscle according to measurement time which was high in the order of thermal treatment, dynamic treatment and cold treatment. The jump height was the highest in the dynamic warm-up with no statistically significant difference for the range of motion of the knee joint. The peak power out at dynamic warm-up and the power of the knee joint were statistically significant according to the treatment and measurement time.

**Conclusion:** Local cold and thermal treatment of femoral muscles at ambient temperature did not improve jump performance, while dynamic warm-up was considered to be effective for maintaining the performance of the activities that require strong muscular power.

**Keywords:** Femoral muscle temperature; Dynamic warm-up; Countermovement jump; Kinematics; Kinetics

## INTRODUCTION

Track and field events are some of the representative sports which require strong muscular strength and instantaneous muscle power (Cissik, 2010; De Villarreal, Kellis, Kraemer & Izquierdo, 2009). As these events are performed outdoor, body temperature of an athlete changes according to surrounding which can play a crucial factor in one's performance level (Racinais & Oksa, 2010; Wendt, Van Loon & Lichtenbelt, 2007).

Falk et al. (1998) reported that there is a decrease in average muscle power at a high temperature due to increase in the central muscle fatigue. Others have reported the adverse effect of high temperature on performance particularly in the events that requires maximum muscle power such as high and long jump (Cochrane, Stannard, Sargeant & Rittweger, 2008; Maxwell, Castle, & Spencer, 2008). Various studies have experimented the use of cold-water treatment and cold-vest treatment to cope the adverse effect of high temperature change on performance. Studies utilizing cold-water treatment method have reported its positive effect on performance due to reduction in the temperature of major muscles (Castle et al., 2006; Duffield & Marino, 2007) whereas, others that used cold-vest treatment method reported no noticeable change in performance or reduction in temperature of the major muscles (Duffield, Dawson, Bishop, Fitzsimons & Lawrence, 2003).

The case differs at low-temperatures where a decrease in cellular metabolism increases the contraction of blood vessels, resulting in decrease in neurotransmission rate which ultimately decreases the muscle contraction rate (Lee, Toner, McArdle, Vrabas & Pandolf, 1997; Swenson, Swärd & Karlsson, 1996). In a study by Mohr, Krustrup, Nybo, Nielsen and Bangsbo (2004) reported that a decrease of 2℃ in lower extremities by a sprinter during a short break of 15~20 minutes could decrease the running performance record by 2.5%, while other studies on external heating of active muscle reported no clear positive or negative effect in physiological or performance benefits such as training-induced hypertrophy or function (Faulkner, Ferguson, Hodder & Havenith, 2013; Stadnyk, Rehrer, Handcock, Meredith-Jones & Cotter, 2018). However, no studies have been conducted to study the effect of high-temperature treatment on the major muscles.

Nevertheless, for events that requires explosive muscle power, warm-up activities including dynamic workout after static stretching are presented as a means to achieve the best motor performance in short periods of time (Chaouachi et al., 2010; De Villarreal, González-Badillo & Izquierdo, 2007). Although, some studies have claimed that increased core muscle temperatures could adversely reduce power-related motor performance which has led to a confusion on the finding the optimal method for maintaining the condition of an athlete during elite sporting competition (Drust, Rasmussen, Mohr, Nielsen & Nybo, 2005).

Therefore, the purpose of our study was to evaluate the effect of passive short-acute temperature therapy of the femoral muscle and dynamic warm-up on the countermovement jump (CMJ) performance and biomechanical variables of the knee joint. The three hypotheses of this study were:

- Cold-temperature treatment (COLD) of the femoral muscles will significantly increase the CMJ performance and the moment and power of the knee joint.
- Thermal treatment (HOT) of the femoral muscles will significantly reduce the CMJ performance and the moment and power of the knee joint.
- Dynamic warm-up (DW) will significantly increase the CMJ performance and the moment and power of the knee joint.

## METHODS

### 1. Participants

20 male athletics players were recruited as participants for the study who are familiar with CMJ (6 long jump, 6 high jump, 5 triple jump, 3 pole vault). Their average age was 20.85±1.90 yrs., the height was 1.81±0.06 m, the weight was 68.55±7.06 kg, and the athletic career was 9.20±2.50 yrs. They participated voluntarily in this study and had no injury to the lower extremity joints and muscles within the last 6 months before participating in the experiment. The public Institutional Bioethics Committee designated by the Ministry of Health and Welfare of Korea approved the research (IRB Number: P01-201707-11-003I to comply with the ethical principles of the Declaration of Helsinki (1975, revised 1983).

### 2. Experimental design & procedures

The pattern of the study was designed as 3 treatments [TREs: two temperature conditions; (HOT, COLD) and DW condition) × 2 time points [TIMEs: pre-measurement (PRE) & post-measurement (POST)]. This study design will allow us to understand the effect of femoral muscle temperature change and DW on lower extremity strength required for the CMJ in terms of biomechanical aspects. Participants visited the laboratory four times once per week including orientation on the first day with experiments in random order of either COLD, HOT and DW treatments per day. The orientation was focused on research procedure, description of the pre-test preparation, stretching, and a practice on DW exercises.

Experiments were carried out in a biomechanics laboratory equipped with dual type constant temperature and humidity sensors (PA030-A2ST-U; AR, KOR). All interventions were performed by maintaining constant ambient temperature and humidity (mean ± SD: 24.0±0.5℃ and 40.0±1.0%) respectively (Colson, Roffino, Mutin-Carnino, Carnino & Petit, 2016). The HOT treatment of the femoral muscles were maintained at 40~45℃ for 15 minutes by using an electric warm pad (TY-20; Swmedi, SKOR) with a thermostat (Cochrane et al., 2008; Lim, Jeong, Lee & Kim, 2011). The COLD treatment was performed by wrapping an ice pack with a cotton towel (T-700; ICE TUBE, GER) to both thigh muscles for 15 minutes by maintaining a temperature of 10~15℃ (Castle et al., 2006; Duffield & Marino, 2007). The temperature of the warm pad and the ice pack was

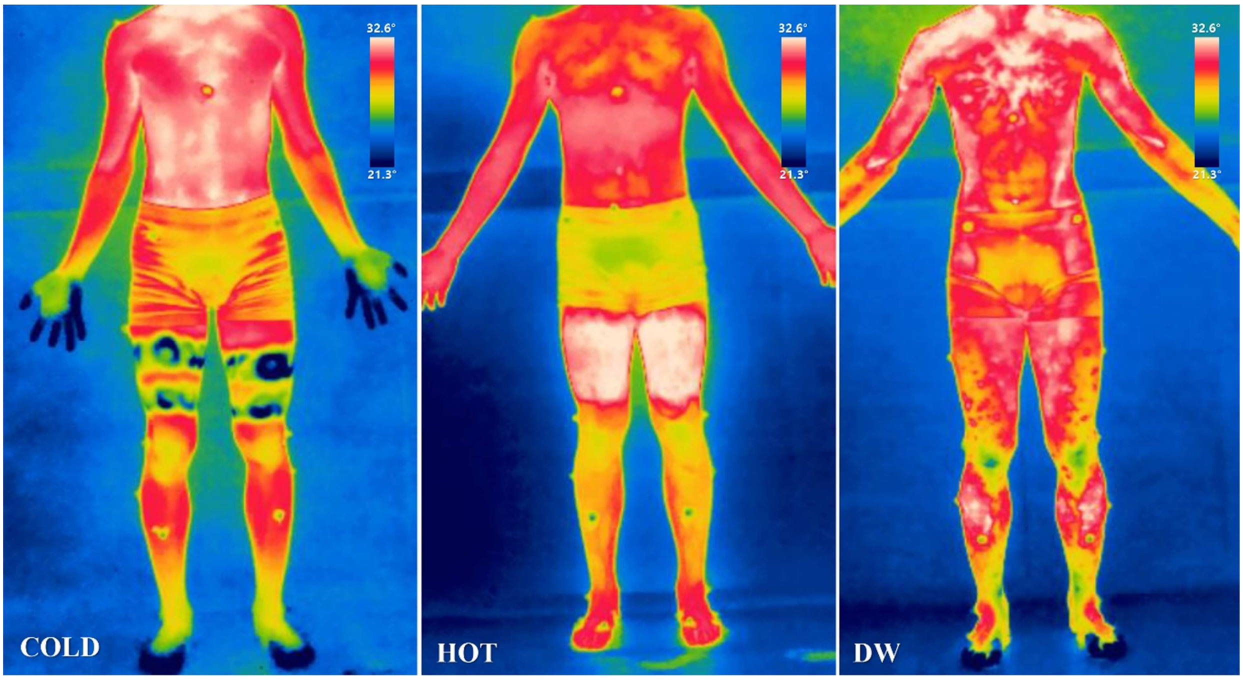


**Figure 1.** A representative measurement result of infrared thermography during three different TREs conditions i.e. COLD, HOT and DW.

maintained using an infrared thermometer (Fluke 62max +, USA) (Lim et al., 2011). The DW treatment was carried out for 15 minutes with a total of 14 whole body movements that included: arm circles forward, arm circles backward, high knee walk, high knee skip, high knee run, Butt kicks, tin soldiers, one leg single-leg stiff-legged walk forward, one leg single-leg stiff-legged walk backward, backward skip, backward run, backpedal, overhead lunge walk and inchworm (Dixon et al., 2010).

The temperature from of both thigh muscles and CMJ performance were measured three times by keeping the arms controlled in anatomical static posture in both PRE and POST (Cochrane et al., 2008; Kim & Eun, 2009). The PRE which is the control condition was performed after 10 minutes of preparation and stretching, While, the POST was performed in the same manner as the pre-measurement but after the intervention. All the participants wore similar experimental clothing after which a total of 47 reflective markers (12 mm) were attached on the major joints (Cappozzo, Cappello, Croce & Pensalfini, 1997; Wu et al., 2002). The CMJ was repeatedly measured 3 times on two force plates (Type 9260AA6; Kistler, SWI) and with 8 Infrared cameras (Oqus 7+; Qualisys, SWE) to record the whole body movement. The body surface temperatures were recorded via a thermographic camera (T650SC; FLIR Systems, Boston, Mass., USA) from equivalent body location of the participants, as shown in Figure 1 (Sanz-López, Martínez-Amat, Hita-Contreras, Valero-Campo & Berzosa, 2016).

## 3. Data analysis

Three-dimensional motion data of the CMJ which is the dependent variable was calculated by applying Butterworth 4th order low pass filter at cut-off frequency 6 Hz, in order to compensate the errors from skin surface movement (McErlain-Naylor, King & Pain, 2014). The ground reaction force data were rectified by applying Butterworth 4th order low pass filter at cut-off frequency 10 Hz, in order to remove the noise included in the analog signal (MacKenzie, Lavers & Wallace, 2014). The visual 3D segment model (v5.01, C-Motion Inc., Rockville, MD, USA) was used for modelling the human body (Kim & Kim, 2009; Kim, Seo & Han, 2012). The variables extracted from the experiment were as follows:

- Femoral muscle temperature ($T_{L.thigh}$ and $T_{R.thigh}$): The femoral muscle temperature was calculated by digitizing each of the femoral central region (right & left thigh) using the package software (FLIR Tools-Software; FLIR Systems, Boston, Mass., USA) supplied with the thermal imaging camera

**Table 1.** Results of change in temperature of the left and right thigh according to TREs and TIMEs (n = 20)

| Variable | COLD | HOT | DW | Partial-eta$^2$ |
|---|---|---|---|---|
| PRE $T_{L.thigh}$ (℃) | 32.37 ± 0.62$^{§}$ | 32.54 ± 0.48$^{§}$ | 32.49 ± 0.47$^{§}$ | 0.078 |
| POST $T_{L.thigh}$ (℃) | 29.18 ± 1.08$^{†ǂ§}$ | 36.88 ± 1.00$^{†‡§}$ | 31.71 ± 0.72$^{ǂ‡§}$ | 0.972 |
| PRE $T_{R.thigh}$ (℃) | 32.39 ± 0.66$^{§}$ | 32.48 ± 0.59$^{§}$ | 32.54 ± 0.37$^{§}$ | 0.061 |
| POST $T_{R.thigh}$ (℃) | 29.37 ± 1.10$^{†ǂ§}$ | 37.27 ± 0.83$^{†‡§}$ | 31.78 ± 0.57$^{ǂ‡§}$ | 0.972 |

[*] Values are in mean ± SD; DW = dynamic warm-up; PRE = pre-treatment; POST = post-treatment; $T_{L.thigh}$ = left thigh skin temperature; $T_{R.thigh}$ = right thigh skin temperature
[†] Significant difference between COLD and HOT at $p < .05$
[ǂ] Significant difference between COLD and DW at $p < .05$
[‡] Significant difference between HOT and DW at $p < .05$
[§] Significant difference between pre and post at $p < .05$

(Hildebrandt, Zeilberger, Ring & Raschner, 2012; Sanz-López et al., 2016). The units are expressed in degree Celsius (℃).

- Normalized centre of mass ($COM_{hei}$): The maximum height of centre of mass (COM) was normalized with the subject's height. The units are expressed in percentages (%).
- Velocity of COM ($COM_{vel}$): The maximum velocity of COM during the jumping phase. The units are expressed in meter per second (m/s).
- Peak power output (PPO): The PPO was calculated by multiplying average vertical ground reaction force and COM vertical velocity (Kilduff, West, Williams & Cook, 2013). The unit is expressed in watt per body mass (W/mass).
- Range of motion of knee joint ($Knee_{ang}$): The flexion angle, abduction angle (internal rotation angle) expressed in degree (°).
- Moment of knee joint ($Knee_{mom}$): The left knee extension moment and right Knee moment was normalized with height and mass and is expressed in N/(mass*ht).
- Power of knee joint ($Knee_{pow}$): The left knee extension power and right knee power was normalized with mass and is expressed in N/kg.

### 4. Statistical analysis

All parameters were expressed as means ± standard deviations. The two-way repeated-measures multivariate analysis of variance (MANOVA) was conducted to verify the differences among dependent variables based on 3 TREs (COLD, HOT and DW) and 2 TIMEs (PRE and POST). The statistical significance level was set at $\alpha = 0.05$. The Bonferroni correction was performed as a post hoc test, and the significance level was set at $\alpha = 0.05$. All statistical analyses were performed using SPSS for Windows Ver. 22 (IBM, Armonk, NY, USA).

## RESULTS

### 1. Effect of temperature of femoral muscles

According to the main effects of the treatment (TREs) and timing (TIMEs), there was a statistically significant difference in temperature of the left and right thigh (Table 1). The Bonferroni adjustments for the PRE for the left and right femoral between TREs did not show any statistical differences. While, the Bonferroni adjustments of POST of left thigh between TREs (COLD 29.18±1.08℃; HOT 36.88±1.00℃; DW 31.71±0.72℃) showed statistically significant differences ($p$ = 0.000, partial-eta$^2$ = 0.972). The Bonferroni adjustment of the POST between TREs of the right thigh (COLD 29.37±1.10℃; HOT 37.27±0.83℃; DW 31.78 ±0.57℃) showed statistically significant differences ($p$ = 0.000, partial-eta$^2$ = 0.972). The Bonferroni correction between left and right thigh between TIMEs showed a statistically significant difference in all three conditions (COLD, HOT and DW).

### 2. Effect of temperature on biomechanical variables

The statistical differences between the main effects of CMJ with TREs and TIMEs were only observed for the $COM_{hei}$ and $COM_{vel}$ (Table 2). The Bonferroni adjustments of $COM_{hei}$ and $COM_{vel}$ during PRE between TREs did not show any statistical differences. While for POST, the Bonferroni adjustments of $COM_{hei}$ between TREs have statistically significant differences (COLD 31.33±3.06%; HOT 31.98±3.06%; DW 34.44±3.33%, $p$ =

0.000, partial-eta$^2$ = 0.792). During POST, the Bonferroni adjustments of $COM_{vel}$ between TREs had statistically significant differences (COLD 3.105±0.123 m/s; HOT 3.146±0.144 m/s; DW 3.282±0.136 m/s, $p$ = 0.000, partial-eta$^2$ = 0.863). Similarly, the Bonferroni adjustment of $COM_{hei}$ and $COM_{vel}$ between TIMEs showed statistically significant only in DW. However, there were no statistical differences in the $Knee_{ang}$ in both TREs and TIMEs.

**Table 2.** Center of Mass (COM), Velocity of COM and ROM of the Knee joint during CMJ based on TREs and TIMEs (n = 20)

| Variable | COLD | HOT | DW | Partial-eta$^2$ |
|---|---|---|---|---|
| PRE $COM_{hei}$ (%) | 31.34 ± 3.39 | 31.57 ± 3.01 | 31.74 ± 2.95§ | 0.045 |
| POST $COM_{hei}$ (%) | 31.33 ± 3.06†ǂ | 31.98 ± 3.06†‡ | 34.44 ± 3.33ǂ‡§ | 0.792 |
| PRE $COM_{vel}$ (m/s) | 3.102 ± 0.171 | 3.134 ± 0.149 | 3.139 ± 0.125 | 0.101 |
| POST $COM_{vel}$ (m/s) | 3.105 ± 0.123†ǂ | 3.146 ± 0.144†‡ | 3.282 ± 0.136ǂ‡ | 0.863 |
| PRE ROM of L. $Knee_{ang}$ (°) | 87.34 ± 11.62 | 88.46 ± 9.32 | 87.47 ± 10.47 | 0.038 |
| POST ROM of L. $Knee_{ang}$ (°) | 90.80 ± 10.60 | 90.85 ± 12.13 | 91.84 ± 11.14 | 0.017 |
| PRE ROM of R. $Knee_{ang}$ (°) | 86.44 ± 12.94 | 87.51 ± 11.25 | 86.82 ± 11.60 | 0.026 |
| POST ROM of R. $Knee_{ang}$ (°) | 90.16 ± 11.04 | 89.91 ± 13.00 | 91.96 ± 12.79 | 0.109 |

[*] Values are mean ± SD; DW = dynamic warm-up; PRE = pre-treatment; POST = post-treatment; $COM_{hei}$ = normalized center of mass; $COM_{vel}$ = velocity of the center of mass; ROM of L. $Knee_{ang}$ = range of motion of the left knee flexion angle; ROM of R. $Knee_{ang}$ = range of motion of the right knee flexion angle
[†] Significant difference between COLD and HOT at $p < .05$
[ǂ] Significant difference between COLD and DW at $p < .05$
[‡] Significant difference between HOT and DW at $p < .05$
[§] Significant difference between pre and post at $p < .05$

**Table 3.** Peak power output and biomechanical changes of the Knee joint (n = 20)

| Variable | COLD | HOT | DW | Partial-eta$^2$ |
|---|---|---|---|---|
| PRE PPO (W/mass) | 4.135 ± 0.477 | 4.149 ± 0.485 | 4.192 ± 0.489§ | 0.096 |
| POST PPO (W/mass) | 4.069 ± 0.392†ǂ | 4.145 ± 0.474†‡ | 4.410 ± 0.411ǂ‡§ | 0.718 |
| PRE L. $Knee_{mom}$ (N/(mass*ht)) | 0.087 ± 0.017 | 0.085 ± 0.015 | 0.089 ± 0.017 | 0.177 |
| POST L. $Knee_{mom}$ (N/(mass*ht)) | 0.087 ± 0.022†ǂ | 0.086 ± 0.021†‡ | 0.093 ± 0.020ǂ‡ | 0.443 |
| PRE R. $Knee_{mom}$ (N/(mass*ht)) | 0.095 ± 0.021 | 0.093 ± 0.021 | 0.096 ± 0.020 | 0.263 |
| POST R. $Knee_{mom}$ (N/(mass*ht)) | 0.096 ± 0.021†ǂ | 0.093 ± 0.019†‡ | 0.102 ± 0.022ǂ‡ | 0.613 |
| PRE L. $Knee_{pow}$ (N/kg) | 1.083 ± 0.310 | 1.029 ± 0.238 | 1.097 ± 0.293 | 0.222 |
| POST L. $Knee_{pow}$ (N/kg) | 1.023 ± 0.281†ǂ | 0.984 ± 0.237†‡ | 1.139 ± 0.293†‡ | 0.686 |
| PRE R. $Knee_{pow}$ (N/kg) | 1.110 ± 0.275§ | 1.069 ± 0.218§ | 1.098 ± 0.259§ | 0.142 |
| POST R. $Knee_{pow}$ (N/kg) | 1.071 ± 0.258†ǂ§ | 1.012 ± 0.223†‡§ | 1.204 ± 0.246†‡§ | 0.758 |

[*] Values are mean ± SD; DW = dynamic warm-up; PRE = pre-treatment; POST = post-treatment; PPO = peak power output; L. $Knee_{mom}$ = left knee extension moment; R. $Knee_{mom}$ = right knee moment; L. $Knee_{pow}$ = left knee extension power; R. $Knee_{pow}$ = right knee power
[†] Significant difference between COLD and HOT at $p < .05$
[ǂ] Significant difference between COLD and DW at $p < .05$
[‡] Significant difference between HOT and DW at $p < .05$
[§] Significant difference between pre and post at $p < .05$

### 3. Peak power output, moment and power of the knee joint

The statistical differences between the main effects of CMJ for TREs and TIMEs were only observed for PPO and $Knee_{mom}$ (Table 3). During PRE, the Bonferroni adjustments of PPO, $Knee_{mom}$, and $Knee_{pow}$ did not show any statistical differences between TREs. For POST, the Bonferroni adjustments of PPO between TREs were significantly higher for DW than for COLD and HOT (COLD 4.069±0.392 W/mass; HOT 4.145±0.474 W/mass; 4.410±0.411 W/mass, $p$ = 0.000, partial-eta$^2$ = 0.718). The Bonferroni adjustment of the PPO between TIMEs showed a statistically significant difference only in DW ($p$ = 0.002, $d$ = 0.417).

The Bonferroni adjustments of left $Knee_{mom}$ between TREs were statistically significant in the order of DW (0.093±0.020 N/(mass*ht)), COLD (0.087±0.022 N/ (mass*ht)) than HOT (0.086 ±0.021 N/(mass*ht)) ($p$ = 0.003, partial-eta$^2$ = 0.443). The Bonferroni adjustments of the right $Knee_{mom}$ between TREs (COLD 0.096±0.021 N/(mass*ht); HOT 0.093±0.019 N/(mass*ht); DW 0.102±0.022 N/(mass*ht)) were statistically significant in the order DW, COLD than HOT ($p$ = 0.002, partial-eta$^2$ = 0.613). While, the Bonferroni adjustment between TIMEs showed no statistically significant differences for left $Knee_{mom}$ and right $Knee_{mom}$.

During POST, the Bonferroni adjustments of left $Knee_{pow}$ between TREs were statistically significant with higher in DW (1.139±0.293 N/kg), COLD (1.023±0.281 N/kg) than HOT (1.029 ±0.238 N/kg) ($p$ = 0.008, partial-eta$^2$ = 0.686). During POST, the Bonferroni adjustments of right $Knee_{pow}$ between TREs were statistically significant in order higher in DW (1.204±0.246 N/kg), COLD (1.071±0.258 N/kg) than HOT (1.012±0.223 N/kg) ($p$ = 0.004, partial-eta$^2$ = 0.758). While, the Bonferroni correction adjustment of the right $Knee_{pow}$ between TIMEs had statistically significant difference.

## DISCUSSION

The purpose of our study was to evaluate the effect of passive short-time temperature therapy (COLD and HOT treatment) of the femoral muscle and DW on the CMJ performance and associated biomechanical variables of the knee joint. In our study, the temperature between PREs and POSTs decreased by 3.11℃ and 4.57℃ for COLD and HOT treatment respectively which were slightly higher than that of the previous studies (Cochrane et al., 2008; Duffield & Marino, 2007; Lim et al., 2011). The temperature between PREs and POSTs during DW treatment fell by 0.77℃ which appeared to be at the level similar to that of the previous study (Cochrane et al., 2008). Sanz-López et al. (2016) reported that any difference in temperature of more than 0.6℃ between lateral side of the body can be regarded as a pathological symptom. In our study, the difference in temperature was below 0.6℃ between left and right legs for PREs and POST which indicated the subjects recruited were free of any adverse pathological symptoms.

The results of this study showed no statistically significant difference between $COM_{hei}$, $COM_{vel}$, and $Knee_{ang}$ of CMJ after COLD and HOT treatment at ambient temperature, while the $COM_{hei}$ and $COM_{vel}$ were significantly increased after DW treatment. Therefore, it is considered that local-acute COLD and HOT treatment of femoral muscles were unlikely to improve CMJ performance. On the other hand, DW treatment which required agility resulted in improved CMJ performance compared to short-time stretching (Knudson, Bennett, Corn, Leick & Smith, 2001). The findings are also consistent with previous studies by Dixon et al. (2010) on the effect of DW and cold water immersion on CMJ which reported that performing warm-up offsets the negative effects of cold exposure.

However, since this study was conducted at ambient temperature, application of excessive DW in a high-temperature environment may cause a decrease in exercise performance due to increased central fatigue and core muscle temperature (Drust et al., 2005; Falk et al., 1998; Maxwell et al., 2008). The PPO used in this study is regarded as a very useful method for evaluating CMJ performance, and has been widely used in several studies (Castle et al., 2006; Cheung & Robinson, 2004; Dixon et al., 2010; Kilduff et al., 2013; West et al., 2016). The cooling treatment (e.g. vest, water, and pack) performed in hot and humid environments has been reported to maintain lower core temperature and contributes to the increase in PPO (Castle et al., 2006). Conversely, at low temperatures passive heat maintenance has a positive effect on improving motor performance by increasing core temperature and PPO (Kilduff et al., 2013). However, cooling of the upper body performed at ambient temperature (22℃ and 40% relative humidity) did not show any statistical difference between PPO and mean power output, which is consistent with the results of the present study (Cheung & Robinson, 2004). Therefore, it can be expected that COLD and HOT treatment at high or low temperature environment may improve the CMJ by increasing the PPO, but not at ambient temperature. On the other hand, DW increased PPO in CMJ and cold water immersion treatment resulted in decreased PPO, which was consistent with the results our study (Dixon et al., 2010; West et al., 2016).

In this study, $Knee_{mom}$ and $Knee_{pow}$ acting on the knee joint were analysed. In result, the effect of DW treatment was only observed for $Knee_{pow}$ although it was higher for only right thigh. It is considered that the increase in core temperature due to DW at ambient temperature can potentially increase the natural transmission rate at peripheral and central nerves (Hill, 1972). However, increasing the temperature of the major muscles is considered to decrease time to peak strength, the time to peak tension, the half relaxation time, and the viscous resistance of the muscles and joints. Thus, considering in terms of the major muscles, there was some agreement with the previous study that low temperature was better for maintaining exercise performance (Bennett, 1984; Bishop, 2003; Davies & Young, 1983; Kilduff et al., 2013).

It appears that local and acute COLD and HOT treatment of femoral muscles at ambient temperature did not improve CMJ performance associated with PPOs and power of the lower extremities around the knee joint. Some of the limitations and recommendation obtained from our study are as follows:

- The COLD and HOT treatments measured were considered not to be in relation to the core temperature, as a result, we were not able to clearly explain the relationship between DW and core temperature.
- In course of study, we considered femoral muscle tension to be one of the important variables to understand how the change in temperature affects the muscle tension which might have an effect on the performance of CMJ. Therefore, we would recommend measuring the core temperature as well as muscle tension before and after treatment in a similar follow-up study.
- Our study showed that local and acute temperature treatment of the main muscle was not effective at ambient temperature so we expect future studies in different environment (high and low).

## CONCLUSION

Exercise at high temperatures has been documented to reduce muscle power due to central fatigue, and the reduction of in core temperature has a positive effect on maintaining exercise performance (Castle et al., 2006; Duffield & Marino, 2007). On the other hand, heat and DW have been reported to have a positive effect on performance at low temperature, because of decreased metabolic rate and neurotransmission rate which reduces the muscle power (Kilduff et al., 2013). However, these studies emphasized maintaining the core temperature and failed to explain the relationship between change in temperature of major muscles and exercise performance. The conclusions obtained from our study indicated that local and acute COLD and HOT treatment of femoral muscle did not improve CMJ performance and lower extremity PPOs around the knee joint. Thus, it was suggested that at ambient temperature, DW or similar warm-up activities performed in the study may be effective in maintaining athletic performance in the process of preparation of a game that requires explosive power within a short duration of time. However, the implication of the study should be conducted with care as the study was conducted at ambient temperature.

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